FIELD REPORT FOR VALIDATION MEASUREMENTS OF SOUNDS PRODUCED BY AIRGUNS ON *M/V GILAVAR* IN THE CHUKCHI SEA ON 21 JULY 2006

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On 21 July 2006 (at ~10:15 local time) two Autonomous Seafloor Acoustic Recorders model B (ASAR-Bs) were deployed on the seafloor ~200 m apart, close to the location 69º 35.85' N, 166º 0.0'W (water depth = 42 m). The recorders have a maximum recording time of about 13 hours at a 44.1 kHz sampling rate, so to maximize recording time their start times were offset. ASAR #2 started recording at 11:00 and ASAR #1 started recording 6 hours later, at 17:00. Between 11:00 on 21 July and 6:00 on 22 July the *M/V Gilavar* followed a course more than 125 km in length designed to provide information on airgun sounds at various distances (~200 m to nearly 35 km), different aspects (bow, stern, and broadside to the vessel) and for two array configurations (one-string and three-string).

Both ASARs were retrieved at ~6:15 on 22 July and 16 GB of acoustic data were downloaded to a laptop computer. Both recorders performed as expected.

The *Gilavar* provided us with time and location information for most of the airgun pulses produced during the recordings. A total of >700 pulses were individually selected and analyzed from most parts of the acoustic records. Groups of 10 consecutive pulses were analyzed about every 10 minutes from all tracks. All or most pulses were analyzed during the few hundred meters preceding and following the *Gilavar*'s closest point of approach (to the ASARs) during each pass. Each analyzed pulse was matched with the location information provided. Broadband sound pressure levels (SPL), which are equivalent to rms (root mean square) levels as used by NMFS for mitigation purposes, were determined for each analyzed pulse. These SPL values were plotted as a function of distance and a sound propagation equation of the type

$$\boldsymbol{RL} = a - b*\log(R) - c*R \qquad \text{Eq. I}$$

was fitted to the data. ***RL*** is the received level and *R* is the distance (m) from the source. Two separate data sets were analyzed:

[1] This revision supersedes the draft of 26 July 2006, in which the distance estimates to 190 dB, 180 dB, 170 dB, and 160 dB were based on a simpler and less appropriate regression approach which did not take scattering and absorption losses into account.

(1) Full array configuration (3 strings, 3147 in^3) – most of the data obtained were with the full array configuration. Data were split into three categories: (a) bow aspect (bow of ship oriented towards ASARs); (b) stern aspect (stern of ship and thus airgun array oriented towards ASARs) and broadside aspect (side of ship oriented towards ASARs). A separate regression was done for sound pressure level data for each of those three categories.

(2) Reduced configuration (1 string, 1149 in^3) – this configuration was used during a few hours in early morning on 22 July. Data were insufficient to split into the three aspect categories mentioned above, so a sound propagation equation was fitted to all pulses analyzed regardless of their aspect (the vast majority of the pulses belonged to the stern aspect category).

Values of *a* (intercept, see Eq. I), *b*, and *c* for the obtained equations are shown in Table 1. The scatter plots and regressions themselves are shown in Figure 1 for the three categories of data obtained with the three-string array, and in Figure 2 for data obtained with the one-string array. The equations shown in Table 1 were used to calculate the distances to 190 dB, 180 dB, 170 dB, 160 dB, and 120 dB re 1 μPa. These distances are shown in Table 2 for the three-string array and Table 3 for the one-string array. Each table also shows the radii predicted by sound propagation modeling done by JASCO Research Ltd. prior to the start of the field season, and the ratios between the field measurements and the predicted values.

With the full three-string array configuration (Table 2), the "field : predicted" ratios for the 190 dB, 180 dB, 170 dB, and 160 dB ranges are 1.2 to 1.9, with most being below 1.5, i.e. the measured values exceeded the modeled values, but generally by no more than a factor of 1.5x. The "field : predicted" ratios for the distances to the 120 dB level were higher, 2.4x to 3.3x. However, the empirical estimates shown in Table 2 are the result of extrapolations over 30+ km beyond the farthest measurement distances. A certain amount of uncertainty is therefore associated with these distances and the resulting ratios.

Table 1: Values for variables *a*, *b*, and *c* (Eq. I) in the regressions (sound propagation equations) fitted to four different data sets: pulses produced with the full array (3 strings), for three different aspects, and pulses produced with the reduced array (1 string). The multiple-*R* value is also shown for each equation as well as the range of distances over which the measurements were made and the sample size (number of pulses analyzed).

	a	*b*	*c*	*R* value	Range of distances (km)	Sample size
Full array						
- bow	248.74	22.02	0.000345	-0.998	0.2–30	193
- stern	248.17	22.66	0.000192	-0.994	0.2–34	153
- broadside	238.12	18.85	0.000436	-0.993	0.5–33	148
Reduced array	255.54	26.55	0.000132	-0.990	0.2–30	239

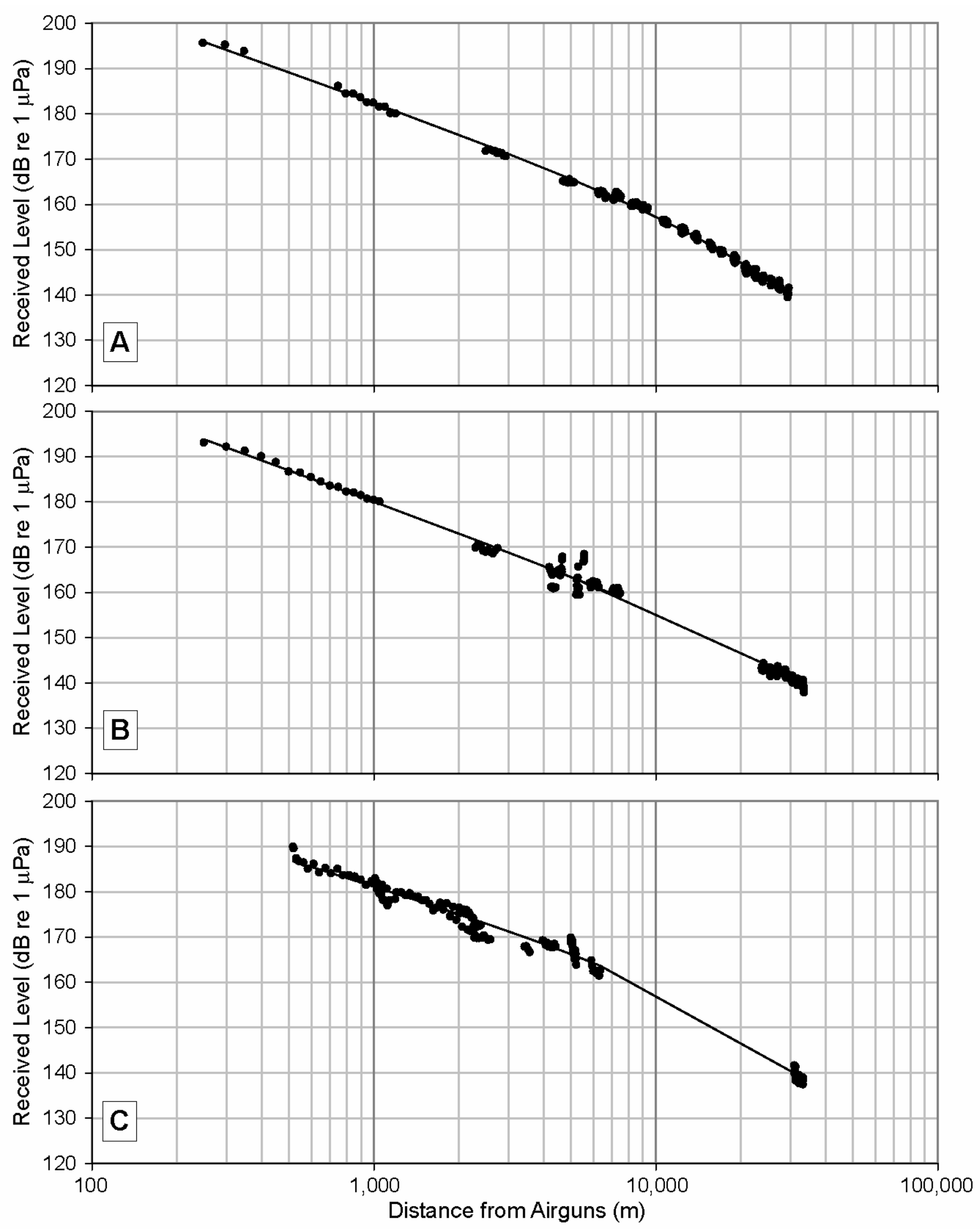

Figure 1: SPL values as a function of range for the three-string array. Equations for the lines shown are in Table 1. ***(A)*** Bow aspect; ***(B)*** Stern aspect; ***(C)*** Broadside aspect.

Table 2: Distances to specified received SPLs obtained for three-string airgun array, and comparison with modeled values. All distance values are in kilometers. The “field : predicted” ratios were calculated with unrounded distances.

	JASCO predictions	Field measurements			“Field : predicted” ratios		
	C_1, 3147 in^3	Bow	Stern	Broadside	Bow	Stern	Broadside
190 dB	0.23	0.44	0.35	0.33	1.9	1.5	1.4
180 dB	0.81	1.2	0.95	1.1	1.5	1.2	1.3
170 dB	2.19	3.2	2.6	3.3	1.5	1.2	1.5
160 dB	4.53	7.7	6.5	8.4	1.7	1.4	1.9
120 dB	26	65	84	62	2.5	3.3	2.4

Table 3: Distances to specified received SPLs obtained for one-string airgun array, and comparison with modeled values. All distance values are in kilometers. The “field : predicted” ratios were calculated with unrounded distances.

	JASCO predictions C_1, 1149 in^3	Field measurements	”Field : predicted” ratios
190 dB	0.26	0.28	1.1
180 dB	0.96	0.67	0.7
170 dB	2.5	1.6	0.6
160 dB	4.7	3.6	0.8
120 dB	35	61	1.7

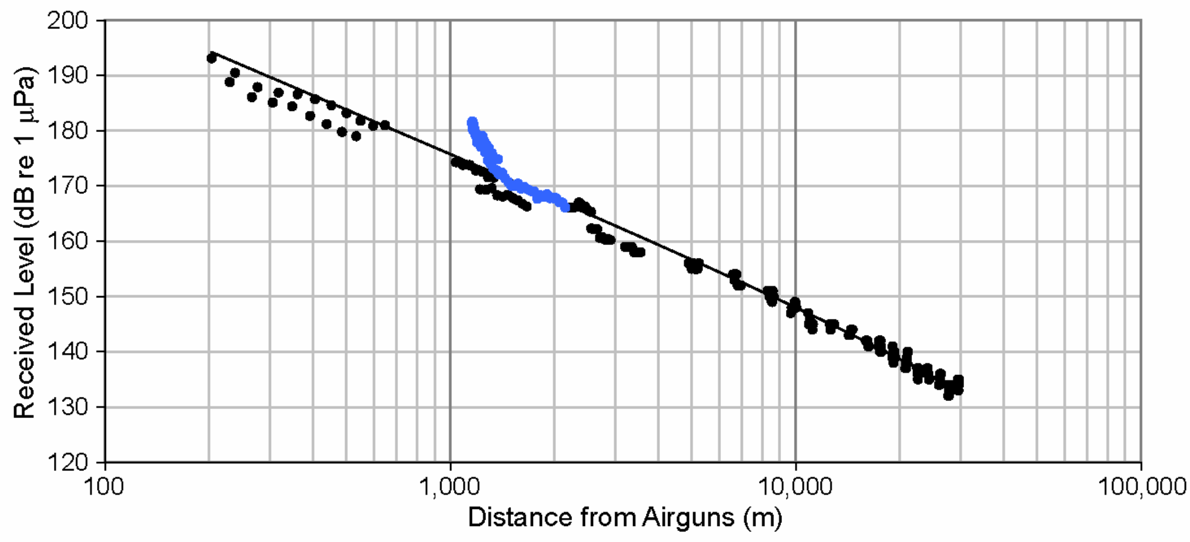

Figure 2: SPL values as a function of range for the one-string array. Stern and bow aspect data are shown in black symbols and broadside data are shown in blue symbols. All data were used in calculating the regression. The equation for the line is in Table 1.

There was good agreement between modeled and empirical values for the reduced array configuration (Table 3). The modeled radii for 180 dB, 170 dB, and 160 dB were actually larger than the empirical values, probably because of aspect effects. Most of the empirical data (~85%) collected with the one-string array fell in the stern aspect category. Broadside data (blue symbols in Fig. 2) were collected during a 2.6 km long southward run ~1.2 km east of the ASARs, with the guns at full volume during the entire run. As the ASARs' latitude was close to the northern end of this run the data became progressively more “stern-like” as the *Gilavar* went south and range increased. For a single-string array aligned parallel to the ship's trackline, we would expect somewhat higher levels at the broadside aspect than from the bow or stern aspects. The empirical data are consistent with this.

Table 4 shows recommended mitigation radii for use by marine mammal observers on the *M/V Gilavar* for both types of arrays. The actual 190 dB, 180 dB, and 160 dB radii will vary depending on aspect (as shown in Table 2) and local conditions. For the ***three-string array*** the maximum of the 3 values (bow, stern, broadside) for each mitigation radius is therefore reasonable as a precautionary estimate and is shown in Table 4. For the ***one-string array***, the recommended mitigation distance for each criterion is the larger of the empirical or predicted distance (from Table 3). For the one-string array, distances in the cross-track (broadside) direction were not measured. As it is likely that the cross-track distances exceeded those in the along-track direction, the precautionary approach is to use the predicted distances where these exceed the measured along-track distances.

Table 4: Mitigation radii based on empirical data.

	Array size	
	Three-string 3147 in^3	One-string 1149 in^3
190 dB	440 m	280 m
180 dB	1200 m	960 m
160 dB	8.4 km	4.7 km

The actual 120 dB (rms) radius is inevitably more variable than are the radii for the higher received levels, given the longer distances that are involved and the effects of local variations in propagation conditions along those long propagation paths. Also, the necessity to use the fitted regression equations to extrapolate beyond the range of distances with empirical data results in some further uncertainty. Given these considerations, plus the different aspects that were involved, the span of the three estimates for the full 3-string array (62 km to 84 km, Table 2) is relatively narrow.